

Cont'd  
D3

[(where  $I_a$  represents a Raman peak intensity at a wavenumber of  $480\text{cm}^{-1}$  for an amorphous component of said channel semiconductor layer and  $I_c$  represents a Raman peak intensity at  $521\text{cm}^{-1}$  for a single crystalline silicon.

Add new claims 29-31.

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--29. The thin film transistor of claim 23 wherein said channel semiconductor layer comprises a laser annealed, non-single crystalline silicon semiconductor layer.

30. The thin film transistor of claim 25 wherein said channel semiconductor layer comprises a laser annealed, non-single crystalline silicon semiconductor layer.

31. The thin film transistor of claim 27 wherein said channel semiconductor layer comprises a laser annealed, non-single crystalline silicon semiconductor layer.--

### REMARKS

Reconsideration and allowance of this application are respectfully requested.

The present invention is directed to a thin film transistor wherein the channel region thereof comprises a non-single crystalline silicon semiconductor layer characterized by (a) oxygen, nitrogen or carbon are contained at a concentration of  $5 \times 10^{19}$  atoms/cm<sup>3</sup> or less in the layer and (b) the semiconductor layer (i) shows a Raman shift at a wave number of

512  $\text{cm}^{-1}$  or higher (claim 23) or (ii) the ratio of the full bandwidth at half maximum (FWHM) of the Raman peak of the channel semiconductor layer to the FWHM of the Raman peak of a single crystalline semiconductor is less than 3 or (iii) the peak intensity ratio  $I_a/I_c$  of the channel semiconductor layer is less than 0.4 where  $I_a$  represents the Raman peak intensity at a wave number of 480  $\text{cm}^{-1}$  for an amorphous component of the channel semiconductor layer and  $I_c$  represents a Raman peak intensity at 521  $\text{cm}^{-1}$  for single crystalline silicon.

As mentioned at page 4, last full paragraph of the specification, Raman spectroscopy is an effective method for evaluating the crystallinity of a material and as discussed in further detail with respect to Figures 2-4, the above criteria corresponding to features (b)(i), (b)(ii) and (b)(iii) are different indicators of the degree of crystallinity of the channel semiconductor layer. Hence, the channel semiconductor layer of the TFT of the present invention is characterized by (a) the presence of carbon, nitrogen or oxygen in an amount less than a predetermined maximum and (b) the presence of a predetermined degree of crystallinity whereby electron mobilities in the non-single crystalline channel semiconductor layer can approximate those obtainable with a single crystalline silicon semiconductor layer. Hence, in the present invention, advantages associated with the ease of fabricating non-single-crystalline silicon can be achieved while at the same time electron mobilities approaching that associated with single crystalline silicon can be obtained. Such a combination of features is particularly advantageous in view of the relative difficulty in fabricating single crystalline silicon layers.

In order to better appreciate the interrelationship of the features (a) and (b) described above, reference should be made to attached Appendices I, II and III. These figures respectively illustrate the interrelationship of

the foregoing features with respect to claim 23 (Fig. 2), claim 25 (Fig. 3) and claim 27 (Fig. 4).

Referring first to Appendix I, the cross-sectioned area in Fig. 2 corresponds to that defined by claim 23. In particular, the cross-sectioned area is defined by those Raman shifts which are greater than  $512\text{ cm}^{-1}$  for impurity concentrations of oxygen less than  $5 \times 10^{19}\text{ atoms/cm}^3$ . Because the non-single-crystalline semiconductor layer of the present invention is characterized by the cross-sectioned region of Figure 2, electron mobilities approaching that of single crystalline silicon can be obtained. In a similar manner, the cross-sectioned areas in appendices II and III illustrate the interrelationship between features (a) and (b) to obtain high electron mobilities. It should be noted, referring to Appendix I that the cross-section area of Figure 2 is within the "melting and crystallizing region" indicated in Figure 2. In particular, referring to the paragraph bridging pages 7 and 8 of the subject application, the "melting and recrystallization region" wherein high carrier mobility was obtained for films falling within this regions. As can be seen in Figure 2, the cross-sectioned region corresponding to that defined by claim 23 is clearly within this region and thus the high electron mobilities associated with the channel semiconductor layer of the present invention are obtained.

Moreover, referring to page 5, second paragraph of the subject application, the region which achieves atomic ordering in the solid phase without undergoing melting (the region to the left of the dotted line in Figure 2) corresponds to a phase which is different from the "melting and crystallization region". The "melting and crystallizing region" corresponds to the portions of the impurity curves of Figure 2 to the right of the upward bend in these curves. It is the upward bend in these curves which signifies a large increase in electron mobility, see page 5, first

paragraph of the subject application.

Similar considerations apply to the criteria of Figures 3 and 4.

Accordingly, due to (a) the presence of carbon nitrogen or oxygen in an amount less than the predetermined maximum recited in the claims and (b) the presence of a predetermined degree of crystallinity, electron mobilities in the non-single crystalline channel semiconductor layer of the TFT of the present invention can approximate those obtainable with a single crystalline silicon semiconductor layer.

Referring to the rejection of claims 23-28 under 35 U.S.C. 112, second paragraph, it is stated that it is not clear whether the Raman Peak (amended to "shift" as supported by the Brief Description of the Drawing for Fig. 2, for example) in claim 23, the ratio of FWHM in claim 25 and the peak intensity ratio  $I_a/I_c$  in claim 27 depend on the kind of impurity present in the silicon - that is, oxygen, nitrogen or carbon or is the indicator independent of the kind of impurity element. The indicators (features (b)(i), (b)(ii) and (b)(iii)) may be indirectly dependent upon the kind of impurity element. That is, as described in the specification the channel layer of the present invention is typically subjected to "laser annealing", see page 2, second full paragraph. However, laser annealing alone will still result in low carrier mobility as described in the paragraph bridging pages 2 and 3 unless a low concentration of carbon, oxygen or nitrogen is also used in accordance with the present invention.

Moreover, as described in the paragraph bridging pages 6 and 7 of the specification, the presence of an excessive amount of carbon, nitrogen or oxygen can impede crystallization of the non-single crystalline layer during laser crystallization thereof. Hence, since the indicators of claims 23, 25 and 27 are indicators of the degree of crystallinity of the non-single-crystalline channel semiconductor layer and since the presence of carbon,

nitrogen or oxygen can impede crystallization of this semiconductor layer, the indicators of claims 23, 25 and 27 may be indirectly dependent upon the oxygen, nitrogen or carbon present in the semiconductor layer. However, it is to be understood that the indicators are directly dependent upon the degree of crystallization of the non-single crystalline layer rather than the kind of impurity element present in the semiconductor.

It is also stated in the Office Action that the claim language limits the impurity element to one of the oxygen, nitrogen or carbon atoms where the specification refers to all of the atoms existing in the silicon. In this regard, it should be noted that there are numerous references in the specification which describe the invention in terms of the carbon, oxygen, or nitrogen impurity being present in the semiconductor and that the presence of all of them is not necessary. Hence, referring to the Brief Description of the Drawings with respect to Figures 2-4 (which respectively illustrate the indicators of claims 25, 27 and 29 as described above with respect to appendices I - III), these figures illustrate electron mobility as a function of (a) the impurity concentration and (b) the indicators of these figures with respect to only oxygen. For example, with respect to Figure 2 (the claim 23 indicator), it is stated that the results for oxygen illustrated in Figure 2 are also observed for both carbon and nitrogen. Also see page 7, first full paragraph in this regard.

With respect to the indicator of claim 25 (Figure 3), see page 8, first full paragraph, where it is again stated that similar results were obtained for nitrogen and carbon compared to the results obtained for oxygen in Figure 3.

Finally, see the paragraph bridging pages 8 and 9 wherein with respect to claim 27 (Fig. 4) is again stated that similar tendencies were observed on the individual effect of nitrogen and carbon concentrations

with respect to the oxygen concentrations illustrated in Figure 4.

Furthermore, see the paragraph bridging pages 9 and 10 of the specification where it is described that "by reducing concentration of each of the foreign atoms" to predetermined levels, the desired high electron mobilities can be obtained. Hence, it is urged that the language of the claims corresponds to that employed in the specification.

Referring to section 4 of the Office Action, claims 23-28 have been rejected under 35 U.S.C. 102(b) over Yamazaki '044. '044 is directed to a TFT which is characterized by a non-single-crystalline channel having a impurity concentration of oxygen, nitrogen or carbon not exceeding  $5 \times 10^{18}$  atoms/cm where the source and drain are selectively crystallized by light with the gate 5G acting as a mask, see column 1, line 55 through column 9, line 14 and the ABSTRACT. Inasmuch as the channel semiconductor layer is not crystallized, it (unlike the source and drain regions) remains in its initial non-single crystalline state which may be amorphous, microcrystalline, or polycrystalline. Hence, the channel region 2 may be pure amorphous where there is no Raman peak and thus no Raman shift can be detected. However, in the present invention, the degree of crystallinity in combination with the low concentration percentage of carbon, nitrogen or oxygen must be such that a Raman peak is present and thus the non-single-crystalline material of the present invention excludes at least the pure amorphous phase of the '044 semiconductor region 2. Hence, the permitted range of crystallinity in claims 23, 25 and 27 is possibly included within the broad range of crystallinity of the channel region in '044; however, the range of crystallinity in the present invention is so selected that the desired electron mobilities of the present invention are obtained.

In this regard, it should be noted that in '044 there is no recognition

whatsoever of the problem addressed and solved in the present invention. That is, as stated above, the phase of the non-single crystalline channel region 2 of '044 may extend from pure amorphous to polycrystalline. As discussed at column 6, lines 8-68 and column 8, lines 6-23 of '044 (referred to in the Office Action), the channel region 2 is formed as a non-single crystal semiconductor layer and thereafter gate insulating layer 3 is formed thereover as stated at column 8, lines 6-23. Although the oxygen, nitrogen or carbon concentration does not exceed  $5 \times 10^{18}$  atoms/cm<sup>3</sup> in the carrier layer, there is no laser crystallization (or any other crystallization) of the channel region 2 prior to forming gate insulating layer 3 thereon. Hence, if channel region 2 is initially formed in the amorphous phase, it will remain in the amorphous phase and will be in this phase in the TFT fabricated in accordance with '044. Note only the source and drain regions 6S and 6D are crystallized and this is effected by utilizing the gate electrode 5G as a mask, see column 8, line 55 through column 9, line 13. From the foregoing it is clear that there is no recognition in the '044 patent to impart to the channel region 2 a desired amount of crystallinity (as may be indicated by the Raman shift, for example) whereby the channel layer due to both the low concentration of the carbon, oxygen and nitrogen impurity and the desired degree of crystallinity is characterized by electron mobilities which approach that of single crystal silicon, as is the case in the present invention.

Note in the present invention, the channel region 602 (Fig. 6) is laser annealed prior to the formation of the gate dielectric 603, see page 16, last two paragraphs. Hence, in the present invention appropriate steps are taken to insure that the channel semiconductor region does have the necessary characteristics to achieve the desired electron mobilities inasmuch as film 602 also contains oxygen, nitrogen or carbon at a concentration of

$10^{19}$  atoms/cm<sup>3</sup> or less, see page 16, second paragraph.

Referring to the remarks made in the Office Action, it is stated that the "channel layer is later (sic) crystallized leaving oxygen, nitrogen or carbon concentration at levels not exceeding  $5 \times 10^{18}$  atoms/cm<sup>3</sup> so that the electron mobility in the channel layer is not decreased. See Yamazaki at column 6, lines 8-68 and at column 8, lines 6-23." It is assumed that "later" and the foregoing quote was intended to be "laser". In any event, as extensively discussed above, the channel region 2 of '044 is not laser (or later) crystallized. Rather, only the source and drain regions in '044 are so crystallized and thus, for the reasons discussed above, there is no recognition in '044 to impart a desired degree of crystallization to the channel region in addition to a low carbon, nitrogen or oxygen concentration thereof to achieve electron mobilities approaching that of single crystalline silicon.

Moreover, it is stated in the Office Action that "With regard to the claim limitations of Raman Peak measurements in claims 23-28 no direct reference in the specification can be made to find indicator relation to the claim structure other than a post construction activity that is for measurement purposes." However, the Raman Peak measurements are a measure of the degree of crystallinity of the channel region as discussed above with respect to page 4 of the subject application and Figures 2-4.

Furthermore, it is stated in the Office Action that "The Raman Peak numbers are all obtained by changing the amount of oxygen, nitrogen, or carbon which as commonly known in the art results in a change of electron mobility." In this regards, as also discussed hereinbefore, the Raman Peak numbers are not obtained by simply changing the amount of oxygen, nitrogen or carbon. Rather, the Raman Peak (shift) numbers may be obtained by subjecting the channel region to laser crystallization to effect



a desired degree of crystallinity therein.

As also discussed hereinbefore, if the oxygen, nitrogen or carbon impurities are below a predetermined level, this facilitates the laser crystallization process. This is particularly important inasmuch as if the laser strength needed to effect the desired degree of crystallization is too high, damage to the channel semiconductor layer can occur. Thus, referring to Appendix IV attached hereto, a laser annealed channel region is illustrated which has been subjected to excessive laser annealing whereby the upper surface of the channel region is roughened, the roughened portion being emphasized for sake of illustration. As can be seen, electron carriers which move in the upper portion of the channel travel a substantially longer path since they move in and out of the ridges in the upper surface of the channel region. Such increase in the electron path length results in decreased switching speed of the transistor.

Moreover, with respect to the voltage applied to the gate, there tends to be a concentration of electrical field at the peaks of the ridges as indicated by the arrows extending across the gate insulating layer. It is at these points that breakdown of the gate insulation tends to occur due to the increased electric field at these points.

From the foregoing, it can be seen that any step which can be taken to reduce the amount of laser (or light) strength needed to effect the desired degree of crystallization of the channel semiconductor layer is particularly advantageous and this is effected in the present invention by insuring that the carbon, nitrogen or oxygen impurities are less than a predetermined minimum, as also extensively discussed hereinbefore.

With respect to the foregoing, dependent claims 29-31, respectively dependent on claims 23, 25 and 27 have been added to recite that the channel semiconductor layer may comprise a laser annealed, non-single

crystalline silicon semiconductor layer.

Referring again to the Office Action, it is stated "The specification refers to similar properties in the paragraph linking pages 8 and 9 by stating that electron mobility is higher for films containing less amorphous components which is a known and inherent property of the recrystallized silicon." As stated above, the silicon in '044 is not recrystallized. Rather, only the source and drain regions of '044 are crystallized by light annealing.

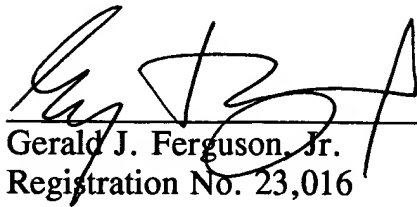
It is also stated in the Office Action that "Therefore the prior art structure also meets the Raman Peak measurement limitation since all the structural limitations and properties related to and resulting in such measurements are anticipated by the cited reference and the particular measurements of the prior art device would result in a similar Raman Peak numbers for the specified impurity concentrations."

As stated above, the '044 structure does not meet the structural limitations and properties recited in the claims. Inasmuch as the non-single crystalline semiconductor channel layer 2 of '044 may extend from pure amorphous to polycrystalline phases and inasmuch as the channel semiconductor region recited in the claims of the subject application most certainly excludes at least pure amorphous materials (for which there is no Raman Peak or shift due to the amorphous state), it follows '044 does not inherently disclose the structures and properties recited in the claims of the subject application. That is, in order for there to be inherency in a prior art structure, the inherent property or structure must be present at all times in the prior art device. It cannot be present sometime and not present at other times. Such an accidental anticipation renders the prior art unsuitable as a reference.

In view of the foregoing amendments and remarks, it is urged this case is now in condition for allowance and a notice to that effect is

requested.

Respectfully submitted,



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